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TECHNOLOGY UTILIZATION

OPTICAL DEVICES: LASERS

A COMPILATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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TECHNOLOGY UTILIZATION OFFICE 1971
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Foreword

The National Aeronautics and Space Administration and Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace and nuclear communities. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the investment in aerospace and nuclear research and development programs.

This compilation is devoted exclusively to an examination of the impact that the rapid development of the laser has brought to optical technology. The contents are divided into two sections, entitled Laser Applications and Laser Devices and Components. The first section contains a brief survey of some of the many ways in which lasers are being applied in measurement of various phenomena in communications, industrial fabrication, and in computer systems. The second section presents descriptions of some NASA- and AEC-originated components, tubes, and techniques used in connection with the generation, modification, or control of a laser beam. This work is not to be regarded as an attempt at complete coverage of the subject. Instead, a sampling of many activities has been included. This is intended to give readers unfamiliar with the technology, a basic look at the scope of these developments, while at the same time presenting certain designs and applications with sufficient detail to attract the interest of designers or engineers engaged in such work.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader's Service Card enclosed in this compilation.

Unless otherwise stated, NASA contemplates no patent action on the technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

RONALD J. PHILIPS, *Director*
Technology Utilization Office
National Aeronautics and Space Administration

Contents

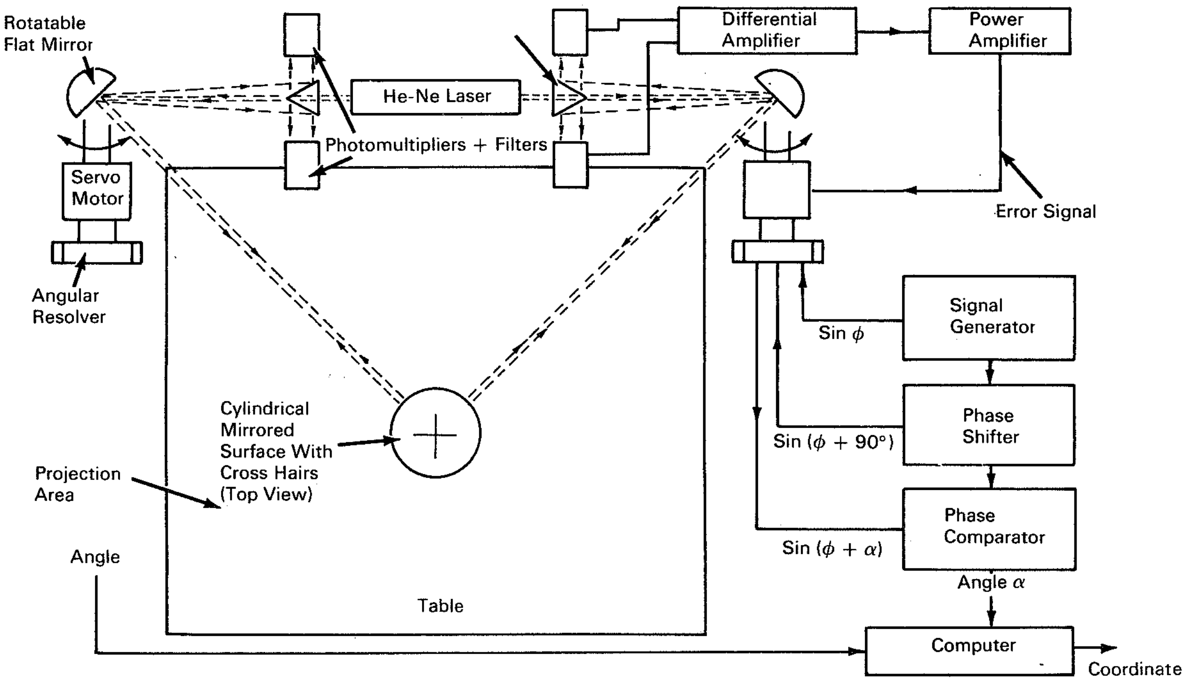
Section 1. Laser Applications

POINT COORDINATE LOCATER

An accurate, easily operated optical measuring system for determining point coordinates on a photograph is provided by an ultraprecision laser ranging apparatus interfaced with a computer. A helium-neon gas CW laser provides light for a null-balancing optical system that replaces the conventional drive-wire measuring system. The system permits accurate location of points on a photograph with no mechanical connection between the ranging apparatus and the photograph.

mirror. (Cross hairs within the cylinder mark the exact point to be determined.) The cylinder reflects each beam back to the plane mirror and the beam splitter where it is divided into two halves.

Each half beam is then directed through an optical filter to a photomultiplier. The photomultiplier outputs are compared in a differential amplifier. An error signal proportional to their difference is amplified and fed to a servomotor, which moves the mirror so that the beam locks on



The system, as shown in the block diagram, consists of a measuring table, a manually positioned cylindrical mirror with centered cross hairs, a helium-neon CW laser and associated optics, an electro-optical servo system, and an angular measurement and readout system.

Circular laser beams pass through a small hole in the beam splitters next to the laser and illuminate two plane mirrors mounted on rotatable shafts. Each mirror reflects its beam onto the projection area where it strikes the cylindrical

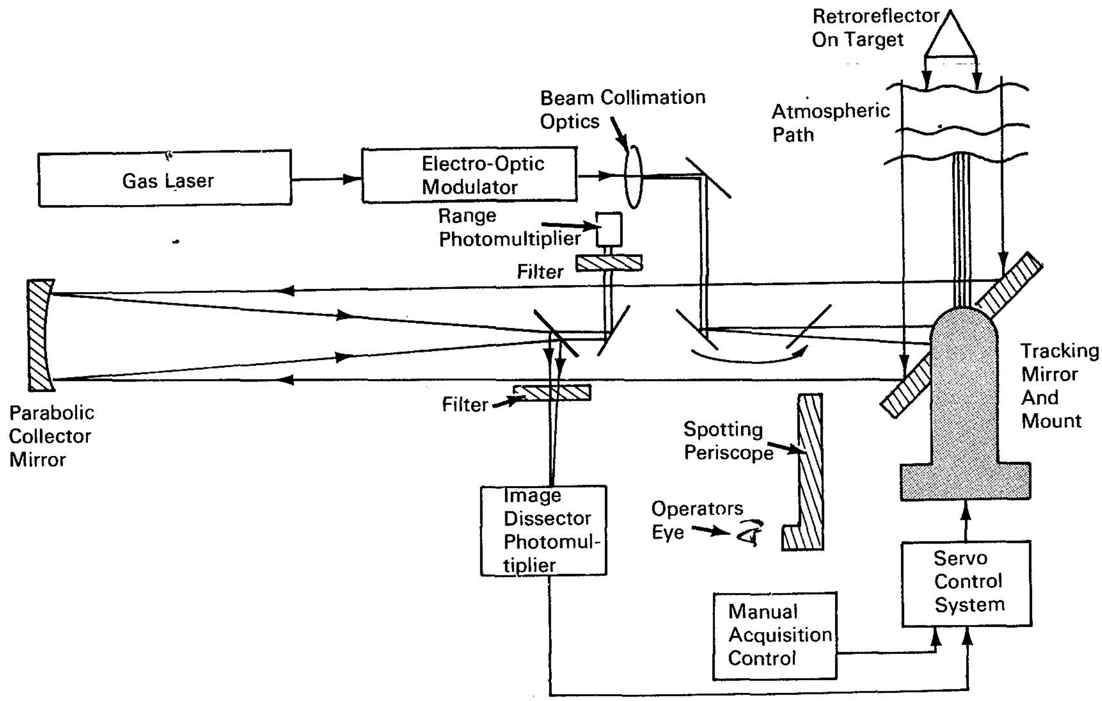
the cylinder. As the cylinder is moved, the rotatable shaft mirrors move to keep the photomultiplier outputs balanced. The shaft angles of the rotatable mirrors then are fed to a computer for calculation of the position of the cross hairs.

Source: R. H. Vonderohe, J. H. Doede, and C. W. Lindenmeyer
Argonne National Laboratories
(ARG-90074)

Circle 1 on Reader's Service Card.

AUTOMATIC LASER TRACKING SYSTEM

A laser tracker with a design similar to a heliostat has been proven capable of tracking a low-acceleration target within about 20 microradians. range to the target. The range accuracy exceeds that which can be provided by a high performance radar.



The basic components of the tracker are a laser, an image dissector, and a servo-controlled tracking mirror The system has been tested both for dynamic characteristics and sensitivity. For low acceleration targets, the tracking accuracy is comparable to that of a startracker. However, the laser tracker has the added capability of measuring

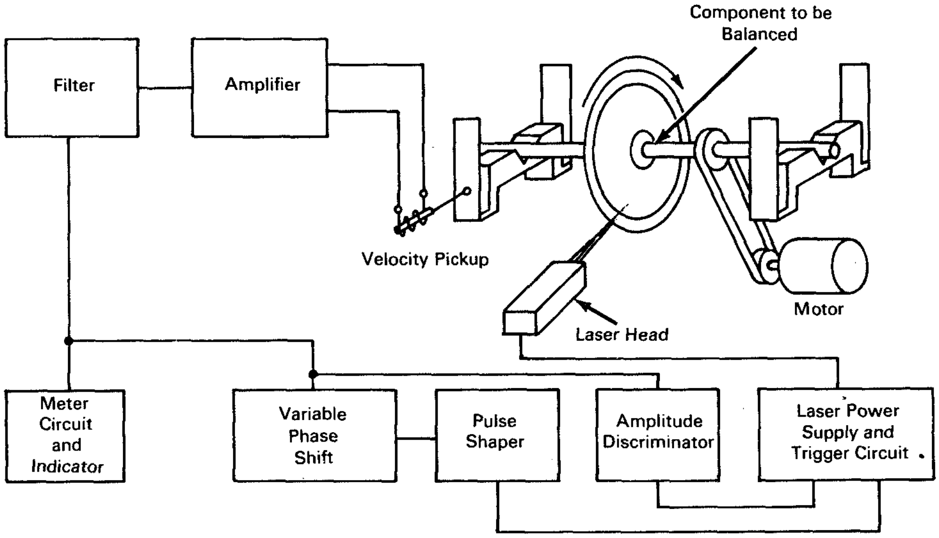
Source: R. F. Lucy, C. J. Peters, E. J. McGann, and K. T. Lang of Sylvania Electronic Systems under contract to Marshall Space Flight Center (MFS-1606)

Circle 2 on Reader's Service Card.

CONCEPT OF ROTARY DYNAMIC BALANCING BY LASER

Rotary dynamic balancing is commonly done by placing a numbered tape around the periphery of a component, cradling it in a suspended floating carriage, and rotating it. The carriage is coupled to a velocity pickup, which produces a voltage output as a result of an imbalance The output triggers a strobe lamp focused on the numbered tape. The number coinciding with the strobe indicates the location of the component's heavy side. By adding weights directly opposite this point, balance can be obtained. The component is then dismounted and material is removed from the heavy side equivalent to the added weight. This method may require rechecking the balance and removal of material several times before desired balance is obtained.

Laser technology now allows high energy monochromatic light to be precisely collimated for welding and machining processes. It is proposed that the present balancing technique be modified by replacing the strobe lamp with a laser head. The imbalance detected by the velocity pickup would



trigger the laser system, which would emit high-energy pulses directed at the component's heavy side. The voltage amplitude from the velocity pickup would control the amount of energy emitted from the laser, and hence the amount of material removed from the component.

Source: W. E. Perkins of North American Rockwell Corp. under contract to Marshall Space Flight Center (MFS-12422)

Circle 3 on Reader's Service Card.

CURIE-POINT SWITCHING FOR THIN FILM MEMORY

Curie-point switching is one method of reversing the direction of magnetization within a selected region. The region is heated past its Curie temperature, then allowed to cool while subjected to a magnetic field having the desired direction and sufficient magnitude to insure switching. The magnitude is, however, too small to affect areas which have not been heated.

Thin films of MnBi about 700 angstroms thick were used as the storage material. The film was heated by a pulsed, high-intensity ruby laser with a focusing cavity and a pinhole aperture, imaged on a microscope stage. When viewed through properly oriented crossed polarizers, the recorded bits of information appear as light spots against a dark background.

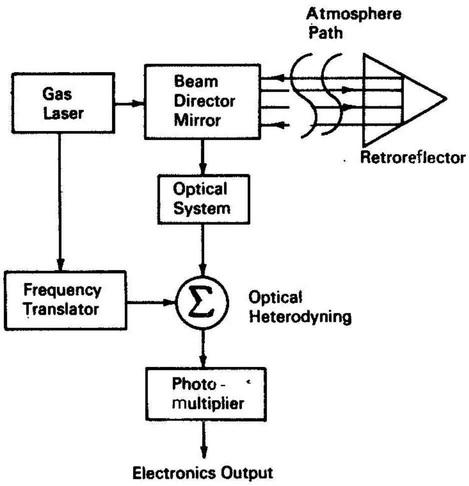
Source: G. W. Lewicki and D. I. Tchernev NASA Pasadena Office (NPO-10402)

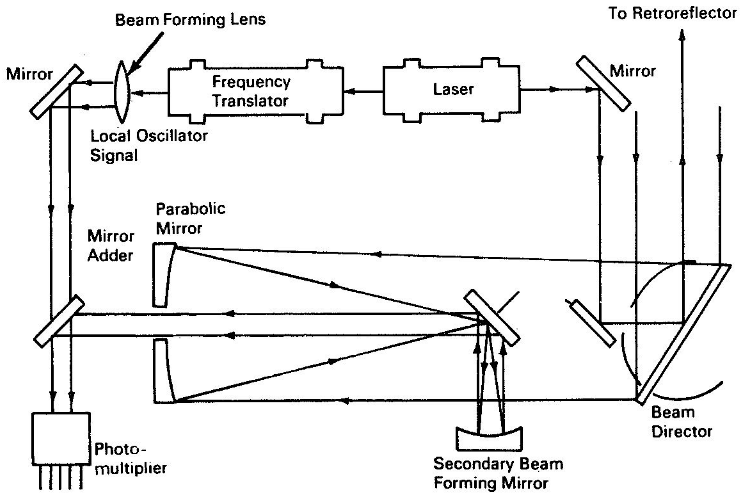
No further documentation is available.

OPTICAL SUPERHETERODYNE RECEIVER WITH LASER LOCAL OSCILLATOR

An optical superheterodyne receiver has been developed to permit reception of AM signals through the atmosphere. The system uses a laser coupled to a frequency translator to supply both the incident and the local oscillator signal in an optical superheterodyne receiver.

The laser output is reflected to the beam director, and thence to the remote retroreflector. The return rays are reflected from the beam director to the parabolic mirror, and then to the secondary beam-forming mirror. This directs the rays through the open center of the parabolic mirror to the adder. Simultaneously, the local oscillator beam passes through the frequency translator





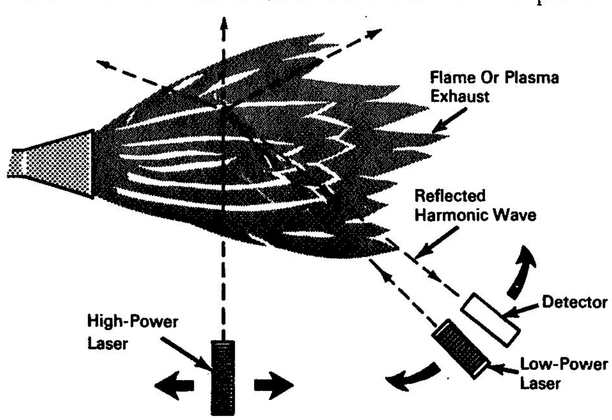
which produces a frequency offset. This beam is focused onto a point which corresponds to the focus produced by the secondary mirror. The collimated return rays are mixed with the local beam at the adder and the resultant difference beat is detected by the photomultiplier and fed to the output circuitry.

Source: R. F. Lucy et al, of
Sylvania Electronic Systems
under contract to
Marshall Space Flight Center
(MFS-1605)

Circle 4 on Reader's Service Card.

CONCEPT OF LASER-BEAM MEASUREMENT OF PLASMA ELECTRON DENSITY

This concept for laser-beam measurement of local electron density in a flame or plasma is based on the theoretical behavior of two plane waves propagating through a nonlinear medium. Refraction of a low-power laser beam in a plasma produces nonlinear polarized waves and a reflected harmonic wave from a point in the plasma. The electron density at this point may be calculated from the amplitude of the reflected harmonic wave. A second, high-power laser beam would create an abrupt dielectric change in the plasma, in order to provide a reflected wave of sufficient amplitude.

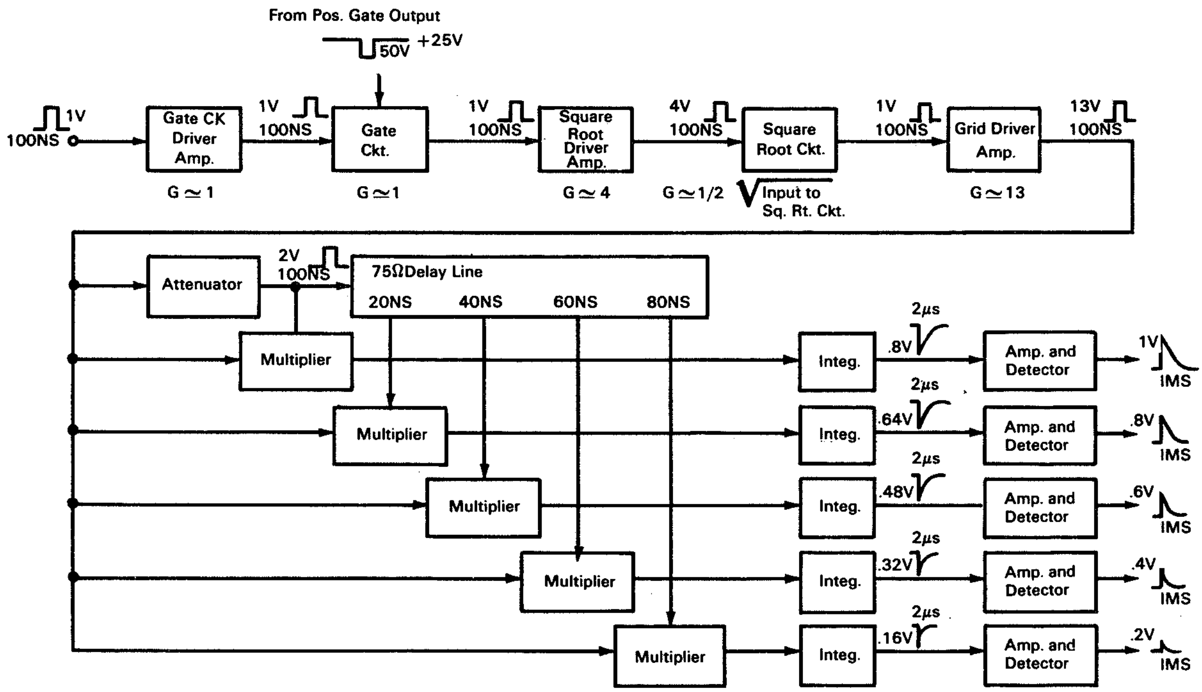


Source: S. E. Longo of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-965)

No further documentation is available.

PULSE AUTOCORRELATION IMPROVES ACCURACY OF LASER SIGNAL DETECTION

A method exists which permits a dispersed laser signal to be discriminated from background noise using a pulse autocorrelator. This device, a block diagram of which is shown, is an electronic



multiplier and integrator network based on the mathematical autocorrelation function and designed to detect multipath (phase-delayed) arrivals of gaussian-shaped signal pulses. The various analog circuit modules are combined to compute the autocorrelation integral.

Two conditions are assumed: Only positive signals are autocorrelated, and the integrators of the practical autocorrelator have long storage times with respect to the duration of individual signal pulses but short storage time compared to the pulse repetition rate. Therefore, each incoming signal pulse is individually autocorrelated, and the output for a particular pulse does not depend upon the autocorrelation coefficients of any previous pulses.

Calibration of the entire autocorrelator is achieved by feeding a train of 100-nanosecond, 1-volt square pulses into the autocorrelator, and then adjusting the gain control potentiometers on the amplification and detection circuits so that the five outputs are proportional to the corresponding theoretical values.

Source: S. J. Campanella of
Melpar, Inc.
under contract to
Manned Spacecraft Center
(MSC-10033)

Circle 5 on Reader's Service Card.

RING LASER ANGLE ENCODER: A CONCEPT

A new type of angle encoder is conceived which would provide continuous digital readout with great precision. It has characteristics particularly applicable to navigation, surveying, antenna or telescope attitude determination, and rotary table angle determination, with improved accuracy. A unique feature is that this encoder measures the angular difference in inertial attitudes of target two at time t_2 relative to target one at time t_1. "Target" means any phenomenon which generates or reflects a detectable light beam.

The encoder combines a ring laser, a scanning photometer autocollimator, and an isolation axis with a rate-servo drive. The ring laser is rotated at an approximately constant rate above a fixed axis. The photometer is rigidly fixed to the ring laser body and its optic axis scans the plane of rotation.

An operation cycle consists of rotating the assembly through 360°. Initially, the plane of the ring laser is oriented to coincide with the angle measurement plane formed by the lines of sight to the two targets. When the first target center is detected, two counts of the ring laser beat are initiated. The first count terminates at detection of the center of the second target. The second count terminates upon redetection of the first target (after 360° rotation). The ratio of these two counts constitutes a measurement of the angle between the two targets.

A single-mode ring laser establishes a standing optical reference wave around a closed path. Typical angular spacing of nodes in a circular ring laser is about one arc second. If boundary loss is sufficiently small, the reference wave remains practically stationary when the ring is rotated. Each antinode of the reference wave is detected by a photosensor as a beat. Beat count, including time interpolation, gives rotation-angle resolution from 0.1 to 0.001 second.

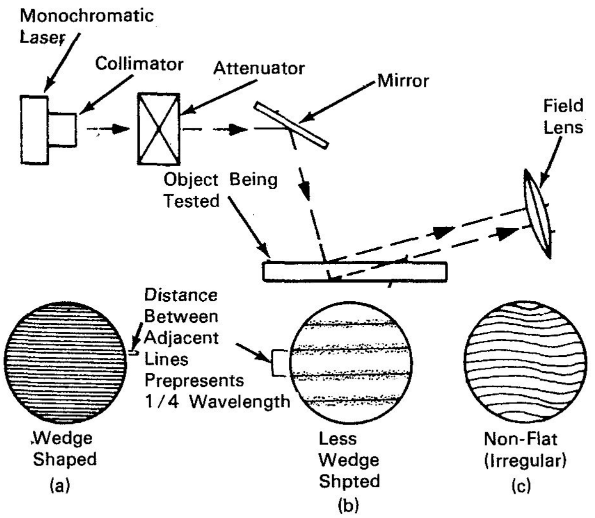
Each target beam is transformed by the photometer optics to an image at the photometer focal plane. The optical axis is defined by a slit aperture at the focal plane. The target image position at the aperture is determined by combination of the photodetector and the scanner estimation logic. This photometer optical axis is related to the ring laser plane by the optics mechanical assembly. This assembly, which transforms the target beams to images at the aperture and relates the image to the laser reference wave, is a critical part of the design.

Source: J. D. Coccoli and J. R. Lawson of
Massachusetts Institute of Technology
under contract to
Manned Spacecraft Center
(MSC-13099)

Circle 6 on Reader's Service Card.

MEASUREMENT OF OPTICAL THICKNESS

Plane parallelism of the opposite surfaces of a transparent object may be measured to within



one-tenth of a micron by using a collimated monochromatic laser beam to illuminate the object under test. The reflections of the beam are projected through a field lens, producing in effect a contour map of the thickness of the object, which reveals the degree of deviation from coplanarity of its opposite faces.

The illustration shows a schematic diagram of the apparatus arrangement, and examples of typical patterns seen through the field lens.

This technique is being used in the precise determination of the wedge-shape of optical crystal samples, in connection with the determination of the electro-optic response of the crystal.

Source: A. R. Johnston and W. A. Hermann
NASA Pasadena Office
(NPO-10666)

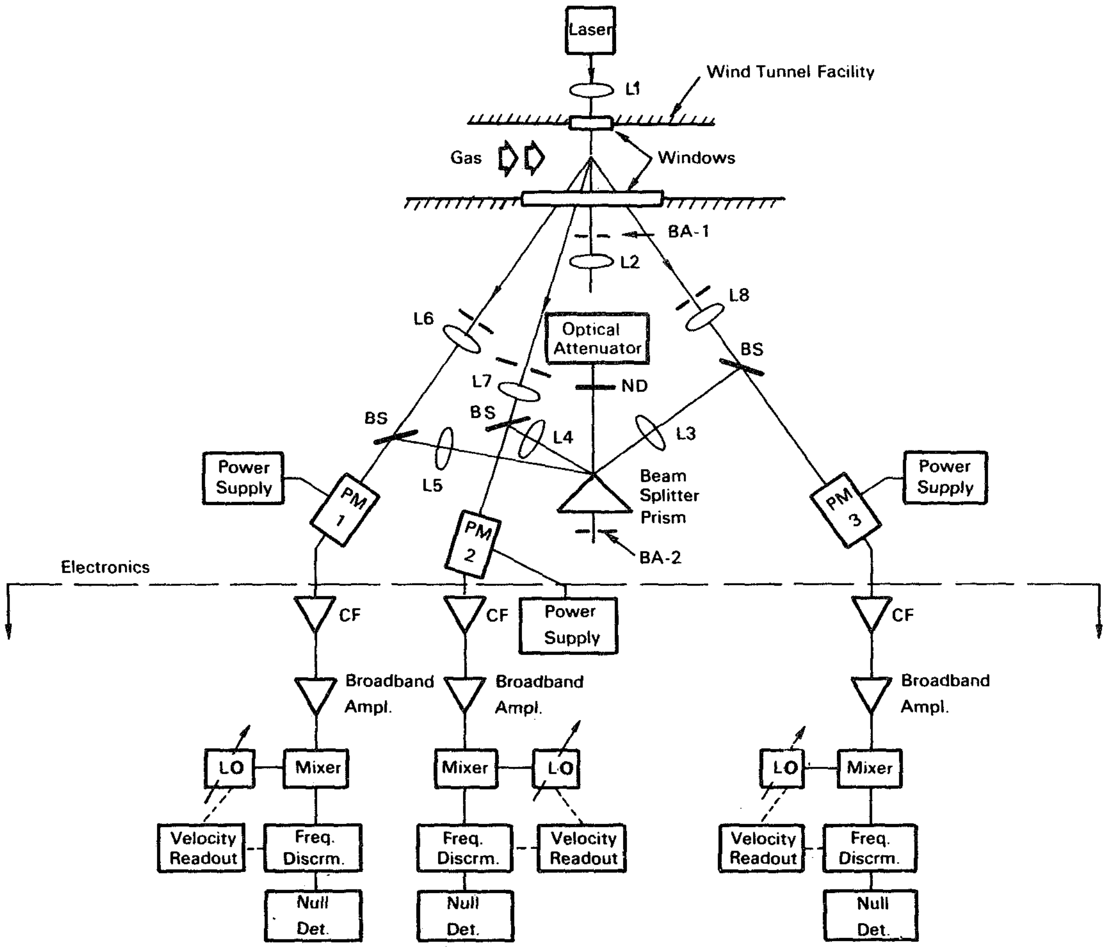
Circle 7 on Reader's Service Card.

DOPPLER-SHIFT GAS VELOCITY MEASUREMENT

A 3-D instrument using a laser source measures both turbulence and mean velocity of subsonic and supersonic gas flows by measuring the Doppler shift of light waves scattered by moving particles in the gas stream. Using an experimental model of the system, gas velocities up to Mach 2 were measured. With smoke injected into the gas flow to provide scattering particles, signal-to-noise ratios of 20 to 30 dB were obtained using a 1-watt argon laser.

The figure shows the essential features of the instrument. The laser beam passes through lens L1 and a window in the wind tunnel or test facility to focus at a selected point in the flow stream. The unscattered beam passes through a boresight alignment aperture (BA-1) and collimator lens L2. The parallel beam then passes through an optical attenuator and neutral density filter (ND) for adjustment of beam intensity. The local oscillator beam is obtained for the three photomultiplier (PM) mixers by dividing the beam with a tetrahedral beam splitter. Lenses focus the local oscillator signals onto the photomultiplier cathodes. A small portion of the beam passes straight through the prism and through a second boresight aperture (BA-2). By using two apertures, a reference baseline is established for alignment of the whole instrument.

Scattered beams are picked up at fixed angles to the laser beam. Lenses L6, 7, and 8 collect scattered light at the chosen angles. After passing through collimating and focusing components, the scattered beams pass through the beam-splitter mirrors (BS), and into the photomultipliers where they are mixed with the local oscillator (unscattered reference) beam.



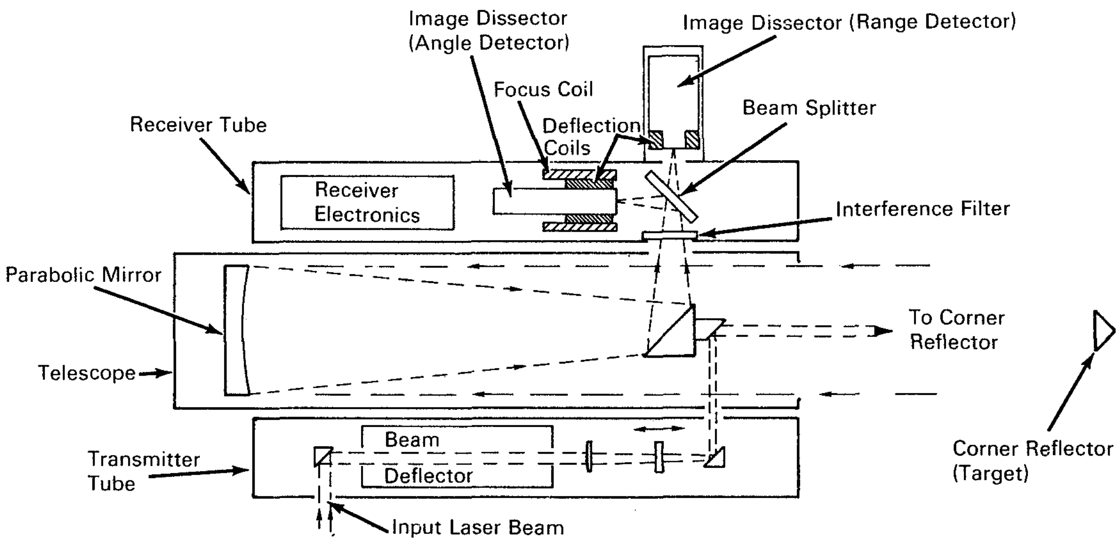
The heterodyne outputs of the photomultipliers are amplified and processed electronically. Spectrum analyzers are used as monitors, while the turbulence and velocity information is obtained by processing through special frequency tracking discriminators, which continuously track the frequency of the fluctuating turbulence Doppler signals. The three orthogonal components of the gas velocity vector are calculated from measurements of the Doppler shift at the three scattering angles.

Source: E. Rolfe, J. K. Silk, S. Booth, K. Meister, and R. M. Young of Raytheon Company under contract to Marshall Space Flight Center (MFS-20039)

Circle 8 on Reader's Service Card.

ELECTRO-OPTICAL TRACKING SYSTEM

A new electro-optical system can track a space vehicle from liftoff to a maximum slant range of 10 kilometers. The system employs a laser beam with an electronic beam deflector and an image dissector. It searches for and acquires the target, then tracks it electronically within a 1° field of view. An ordinary optical tracking system is greatly improved by the addition of this electronically scanning transmitter and receiver. In addition to search and acquisition scanning, this system permits the transmitter and receiver to track rapid movements or accelerations of the target.



The components of the telescope assembly are contained in three aluminum tubes and a small electronics chassis, all supported by a bezel casting, which is designed to mount directly onto the elevation gimbal of an existing tracking pedestal. The transmitter tube contains the beam deflector, which can electronically steer the laser beam in two dimensions with maximum deflections of approximately ± 0.33 degree. Collimating lenses magnify this to ± 0.50 degree and adjust the output laser beamwidth to a nominal 1/44 degree. The receiver tube contains a standard image dissector, a photomultiplier with an imaging section that allows its small instantaneous field of view to be scanned in two dimensions. The ultimate accuracy of the system is provided by the image dissector, which performs like a startracker with an electronically controllable bias. The telescope in the central tube is a simple Newtonian astronomical unit. It images a 1° × 1° field of view onto the photocathode of the image dissector.

Control electronics, system logic circuitry, and power supplies are contained in external cabinets (not shown on the illustration).

Source: R. E. Johnson and P. F. Weiss of Sylvania Electronic Systems under contract to Marshall Space Flight Center (MFS-14791)

Circle 9 on Reader's Service Card.

IMPROVED PHOTOLUMINESCENT DOSIMETER SENSITIVITY

A new device employs an ultraviolet laser to increase the readout sensitivity of photoluminescent dosimetry systems. The sensitivity of prior dosimeters was limited to relatively large radiation doses (about one roentgen), because of light emitted by predose fluorescence and because of the visible light produced by conventional ultraviolet sources.

The problem was overcome by modifying a standard dosimeter. An electronic gate was added to trigger the intensity level photomultiplier The gate is controlled by a second photomultiplier, which senses a short (10 to 20 nanosecond) ultraviolet pulse from a laser used to excite the dosimeter. The gate provides a time delay, preventing the photomultiplier from reading light from predose fluorescence. The laser provides fast cutoff of the excitation source and generates essentially no visible light.

The modified dosimeter was tested by removing its ultraviolet source and cutting a hole in its back panel to introduce the laser beam. The gate triggered the photomultiplier after a 1-5 microsecond delay. The photomultiplier response was observed on an oscilloscope. Preliminary studies have indicated that the sensitivity of the dosimeter could be improved by at least two orders of magnitude.

Source: J. Kastner, A. Longnecker, and D. Eggenberger
Argonne National Laboratory,
and D. King and D. Schutt of
University of Notre Dame
(ARG-10109)

Circle 10 on Reader's Service Card.

EXPERIMENTAL SETUPS FOR STUDYING THE ANGULAR AND SPECTRAL DISTRIBUTIONS OF DIFFUSELY REFLECTED LIGHT

The experimental apparatus diagrammed in Figure 1 is used to investigate the angular distribution of "diffuse" reflectance from cathodochromic

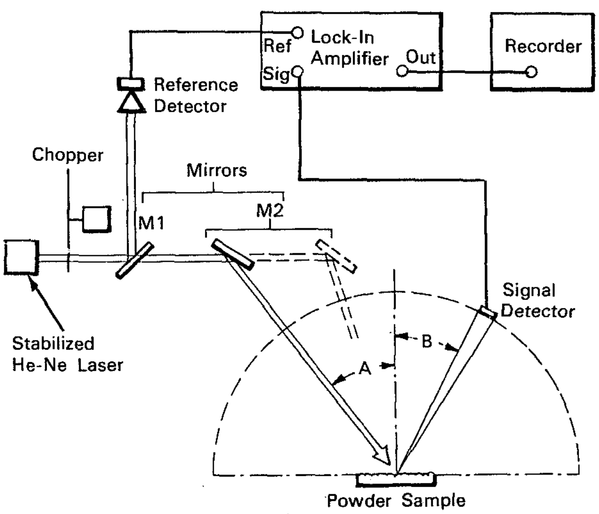


Figure 1

powders; Figure 2 shows a cross-sectional view of the apparatus used for measuring the total spectral reflectance of the powders. Both experiments use a sample holder which remains upright, allowing the reflectance of loose powder samples to be measured without the use of a cover glass. This eliminates the error-causing reflectance of the glass itself.

In the first experiment, the light source used is a stabilized He-Ne laser operating at 6328 Å. The mirror M2 can be translated and rotated as indicated to vary the angle of incidence A of the laser beam on the powder surface. The signal detector is manually rotated along an arc of an 8-in. diameter circle centered at the point where the incident beam intersects the powder surface. The incident beam actually enters with a slight inclination to the plane of the paper. This inclination allows the detector to move through the full 180° arc without blocking the incident beam. The angle of inclination is adjusted, however, so that any laser light specularly reflected from the powder surface still intersects the detector arc and is therefore observed at the appropriate angle of reflection B. The 2° aperture of the signal detector limits the accuracy of the system to $\pm 1°$.

The detection electronics are comprised of a lock-in amplifier and an x-y chart recorder. The laser beam is modulated at 30 Hz by a mechanical chopper. A few percent of the direct chopped laser light is reflected to a reference detector by an uncoated glass plate, M1.

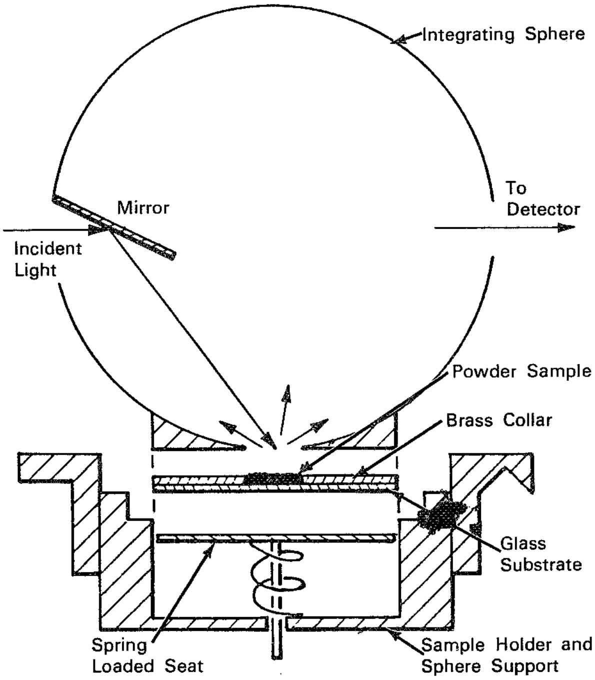


Figure 2

In the second experiment, a new sample holder and sphere support assembly accurately positions the powder sample in a modified, inverted integrating sphere. The powder samples are prepared in the standard manner within a brass collar cemented onto a glass substrate, but without the quartz cover formerly required. The prepared sample is placed in the new holder atop a spring-loaded seat. When the inverted sphere is placed in position the spring is compressed, assuring close contact between the powder surface and the sample aperture plane of the sphere. Both the sphere and the sample can be easily removed and replaced. In addition, photochromic samples can be optically switched in position, and reliable reflectance data obtained within a few seconds.

Source: R. C. Duncan and R. Infanti of
Radio Corp. of America
under contract to
Goddard Space Flight Center
(GSC-11132 & 11143)

No further documentation is available.

FEASIBILITY OF WIRELESS POWER TRANSMISSION

Is it feasible to use microwave or laser energy for wireless transfer of power from a manned, Earth-orbiting central station to unmanned satellite substations? Details of such a power-transfer system have not been established. Therefore, the possibility of wireless power transfer has been judged on the basis of the state of research and development in power generation, transmission, and conversion.

Existing microwave power generation is more than adequate for the estimated 2 kW requirement of a satellite substation. Generators such as superpower Amplitrons have a continuous output exceeding 400 kW at a wavelength of 10 cm. In a power system with an overall efficiency of 18 percent, an Amplitron could supply power for several substations.

Power transmission requires higher efficiency than is acceptable for present radar and communication systems. One idea for improving efficiency is to form a convergent beam in an ellipsoidal transmission "envelope." Calculations show that antenna size can be reduced as wavelength is reduced. However, generator efficiency also diminishes with shorter wavelength. The implication is that improvement of generator efficiency for operation at shorter wavelengths (less than 3 cm) would permit a significant reduction in antenna size.

High-power laser development, being newer, is behind microwave technology. The highest continuous power output obtained from a laser is still far less than that available with microwave techniques. Despite the short history of its development, however, laser power generation is progressing rapidly; output power levels have been increasing severalfold per year.

Laser power transmission and conversion are still in the research stage. One goal of research in power transmission is to obtain a long-lived refractor that will withstand high-power radiation. Lenses of doped and ultrapure germanium are being tested for this use. Laser energy has been converted to electric power by means of photovoltaic detectors. Semiconductor p-n junctions of Cd-Hg-Te alloys can be made for efficient operation at the CO_2 laser wavelength.

Calculations similar to those made for microwave antenna size show that transmission and receiving apertures would be much smaller for the laser beam. This offers a special advantage over a microwave system, which must compromise between transfer efficiency and antenna size.

Source: W. J. Robinson, Jr.
Marshall Space Flight Center
(MFS-14691)

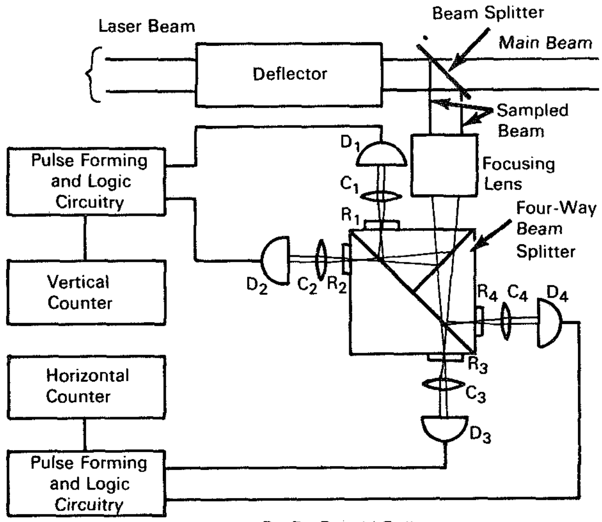
Circle 11 on Reader's Service Card.

Section 2. Laser Devices and Components

DIGITAL BEAM-DEFLECTION SENSOR

This sensor detects the two-dimensional deflection angles of a laser beam to provide servocontrol of beam direction. The sensor incorporates beam splitters, focusing and condensing lenses, Ronchi rulings, photodetectors, and pulse forming and logic circuitry. Reported accuracy is about four times that of other angle-sensing systems.

A portion of the deflected beam, sampled by the beam splitter, is focused onto a four-way beam splitter, which allows the focused beam to fall on each of four Ronchi rulings which are placed in the split focal plane. Two of the rulings, R_1 and R_2, are set with horizontal lines and the other two, R_3 and R_4, are set vertically. The two sets of rulings are perpendicular to each other within ± 0.1 milliradian. As the spot of focused light moves across the alternate opaque and transparent stripes of the rulings, pulses of light are transmitted to the photodetectors which give electrical output pulses corresponding to beam movement. Positive- and negative-going deflections are discriminated by sensing the relative phases from each pair of photodetectors connected to the pulse forming and logic circuitry. The resultant pulses are counted as dictated by the pulse phases to establish the beam position.



R_1-R_4 Ronchi Rulings

C_1-C_4 Condensing Lenses

D_1-D_4 Photodetectors

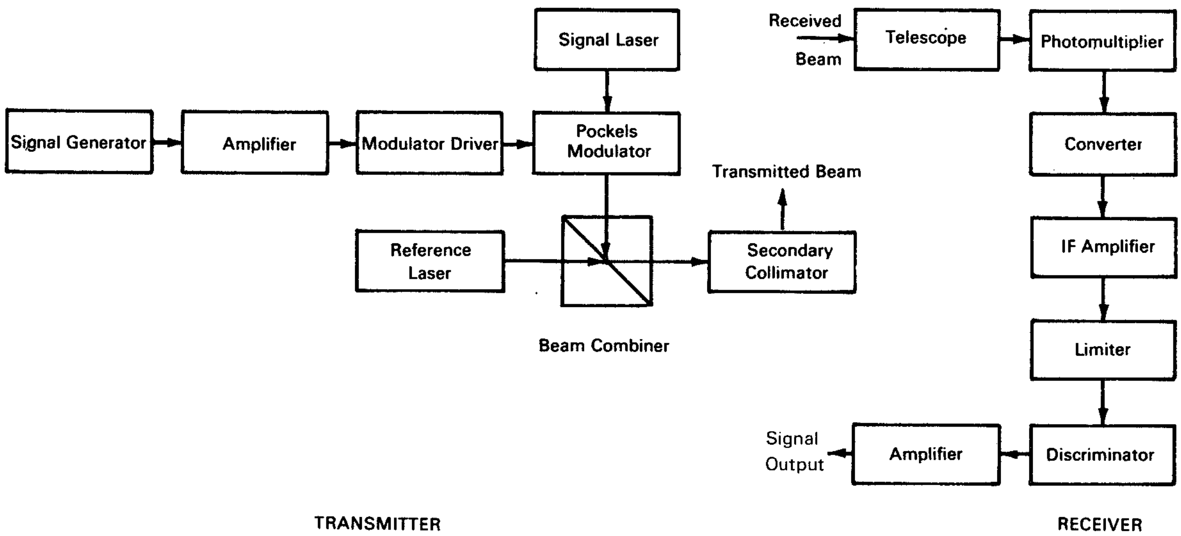
Source: V. J. Fowler of
General Telephone and Electronics, Inc.
under contract to
Marshall Space Flight Center
(MFS-14785)

Circle 12 on Reader's Service Card.

ELIMINATION OF ATMOSPHERIC NOISE IN LASER COMMUNICATIONS

An optical communication system has been made insensitive to atmospherically-induced amplitude fluctuations and phase distortions by using an angle-modulated, transmitted reference, heterodyne laser system. The block diagram shows an implementation of the system for single-frequency subcarrier modulation.

The modulation waveform (intelligence) derived from the signal generator is amplified and applied to a Pockels cell modulator (using a 45° Y-cut ADP crystal) that phase modulates the signal laser beam in synchronism with the modulation waveform. The signal and reference beam lasers are tuned, servo-locked, and stabilized to a dif-



ference frequency of 300 MHz. The beams are collimated, combined, and transmitted through the atmosphere. At the receiver, the beam is focused on a photomultiplier detector and the difference frequency is generated. The 300 MHz difference signal is converted to a 60 MHz second IF, amplified, limited, and discriminated to recover the modulation waveform.

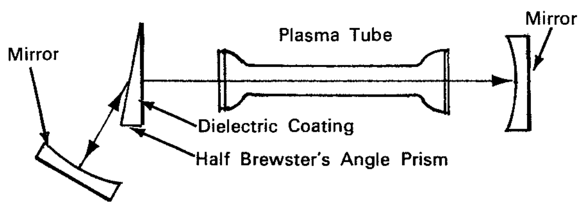
Source: J. N. Packard of
Aircraft Armaments, Inc.
under contract to
Goddard Space Flight Center
(XGS-10396)

Circle 13 on Reader's Service Card.

THREE-MIRROR FABRY-PEROT LASERS

Linear Fabry-Perot lasers have been operated with a third internal mirror in the form of a half Brewster's angle prism, as shown in the figure.

By placing the rear surface of the internal mirror at Brewster's angle, reflection losses are avoided.



The prism may be mounted on a slide providing motion perpendicular to the plane of the drawing, in which case the prism may be moved to bring surfaces of differing reflectivity into position in the beam.

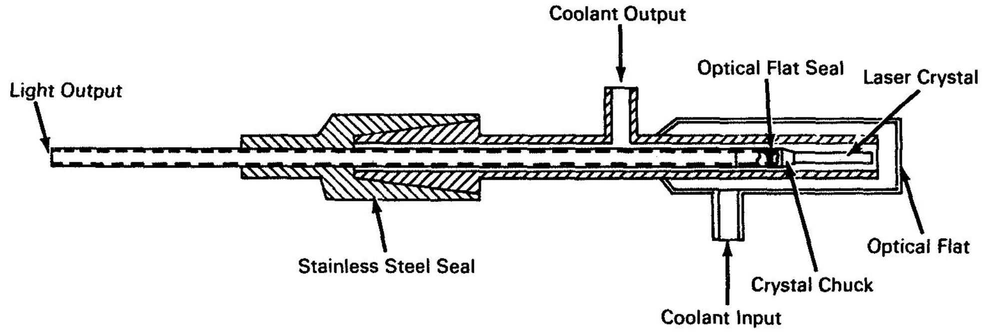
Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14037)

No further documentation is available.

FLOW TUBE COOLING FOR SOLAR-PUMPED LASER

The illustrated flow tube has been constructed to provide two major functions in the application of a laser beam for transmission of both sound and video. First, it maintains the YAG laser at the proper operating temperature of 300°K under solar pumping conditions; and, second, it serves as pump cavity for the laser crystal.

The flow tube includes a small four-jaw chuck



that holds the laser crystal in place. Cooling is accomplished by forcing water through the flow tube and through a heat exchanger mounted in a cool water bath. Deionized water is used to prevent contamination of the crystal end reflectors. The coolant section also serves as the pump cavity. The inside walls are silver plated to reflect pump light entering the flow tube at other than normal incidence so that efficient use can be made of available pump power.

Source: Radio Corp. of America
under contract to
Manned Spacecraft Center
(MSC-11026)

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COOLANTS WITH SELECTIVE OPTICAL FILTERING CHARACTERISTICS FOR RUBY LASER APPLICATIONS

Two common ruby laser pumping techniques employ large amounts of ultraviolet light. Although, in general, increases in ultraviolet light level will give larger output pulses, a study has shown that ultraviolet light of certain frequencies is actually detrimental to peak power output. It is essential, therefore, to find a way to filter out the unwanted frequencies.

Another major problem in the operation of ruby lasers is crystal heating during pumping. Vapors from liquid nitrogen have been used to cool the crystals in the past, but a liquid coolant between the flashtube and the crystal would have several advantages.

A suitable liquid has been found to serve both as a coolant and as a medium for filtering out undesirable flashtube emissions. It consists of a solution of copper sulfate in a 4:1 volumetric mixture of ethanol and methanol. This solution should be useful with ruby laser systems, particularly in large pulse or Q-switching applications, which experience the greatest harmful effect of the far-ultraviolet flashtube emission.

A principal feature of this solution is its ability to absorb strongly all wavelengths below 3000 Å, and yet remain almost transparent to light in the pump-band regions for the ruby crystal. A copper sulfate concentration sufficient to absorb essentially all wavelengths below 3000 Å within a given optical path length reduces the transmittance of light in the ruby pump bands by only a few percent.

Source: J. R. Rasquin
Marshall Space Flight Center
and F. R. McDevitt of
Auburn University
under contract to
Marshall Space Flight Center
(MFS-20188)

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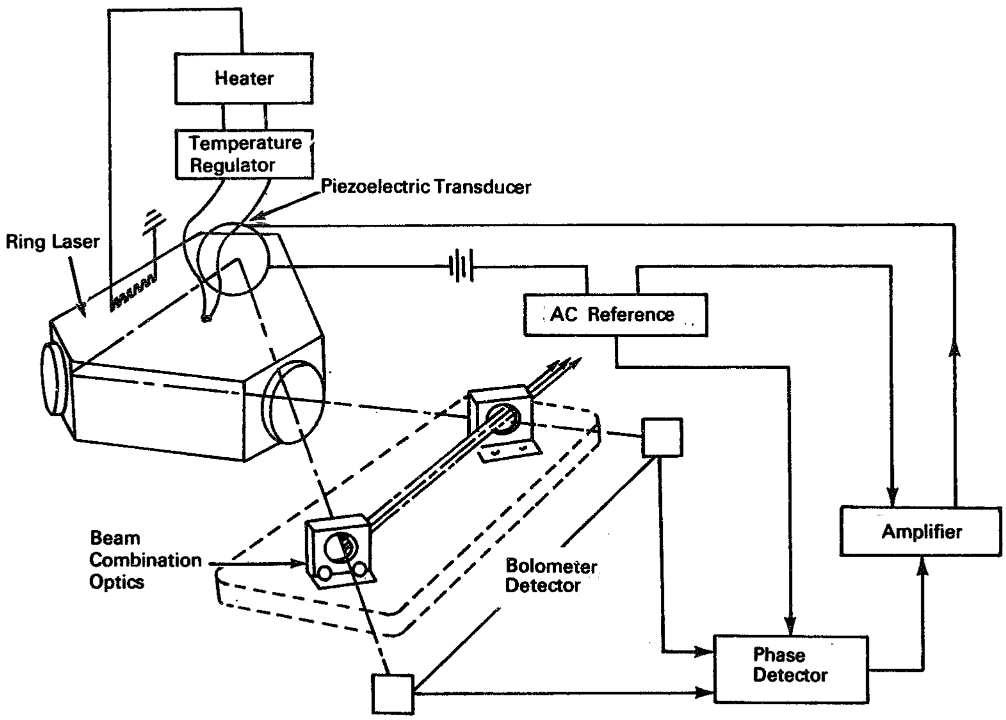
LASER FREQUENCY STABILIZATION CONCEPTS



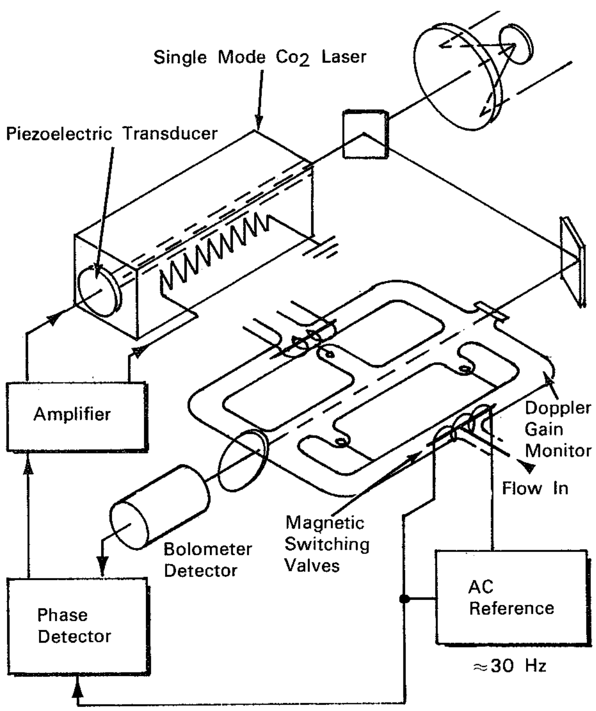
Design concepts for laser frequency stabilization have been evolved through theoretical and experimental work with a carbon dioxide laser. Several concepts are described, each based on generation of a deviation signal which corrects the laser operating frequency.

Two approaches are described. The first concerns systems using a frequency-dithered ring laser. This approach depends on competition between the clockwise and counterclockwise beams resulting in a sharp switching action on beam intensity. This switching point occurs at a unique frequency and can be used as a frequency deviation reference.

The stabilized ring laser is frequency dithered by applying a sinusoidal voltage to a piezoelectric element which drives one mirror, thereby changing cavity length. The intensity-modulated beam produces an ac signal at the detector output. The duty cycle of this signal varies with the laser operating point.

The control signal is derived by comparing the ac signal to the dither voltage in a phase sensitive demodulator. After amplification, the control voltage is applied to the piezoelectric transducer to correct the cavity length. Operating as a null-seeking system, the stabilization loop cancels thermal and other disturbances.

The second approach concerns systems which



Frequency Stabilized Linear Laser Using Doppler Gain Tube use a Doppler gain tube. This sort of frequency stabilization has the advantage that modulation for frequency control can be done externally, with negligible optical coupling back to the laser itself. The gain modulation effect associated with the direction of gas flow in the gain tube is used to obtain a frequency discriminant. The gain modulation depth and phase (referred to the flow modulation frequency), depend on the laser operating point relative to the gain-vs-frequency profile of the Doppler gain tube.

To achieve stabilization, a portion of the output of the linear laser is directed into the gain tube. In the tube the flow of gas is modulated by solenoid valves to give a cyclic flow velocity ± v in the discharge. Upon passing through the gain tube, the amount of modulation of the laser beam depends on the laser frequency and the direction of gas flow. The signal from the thermistor bolometer is an ac voltage at the frequency of the flow modulation. Demodulation takes place in a phase sensitive demodulator operating with a reference derived from the solenoid valve modulation voltage. The amplified output of the demodulator is applied to the linear laser cavity to correct its length.

Source: H. Mocker of
Honeywell Inc.
under contract to
Marshall Space Flight Center
(MFS-2448)

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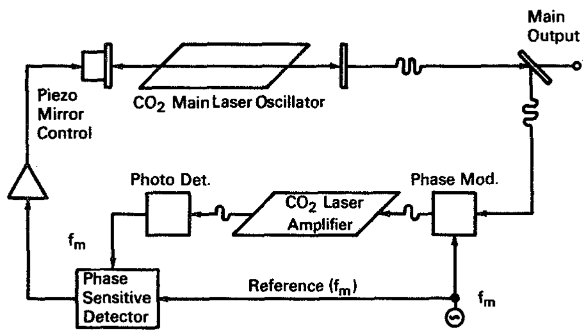
LASER OSCILLATOR FREQUENCY STABILIZATION

Long-term absolute frequency stabilization of a laser oscillator can be obtained if the laser's oscillation frequency is referenced to the exact center (or some other reproducible feature) of an atomic transition. Several techniques have been demonstrated for obtaining an error signal if the frequency of a laser changes.

In the technique illustrated in the figure, a portion of the output of an unmodulated CO_2 laser oscillator is phase modulated with a frequency f_m, and passed through a reference CO_2 laser amplifier that is operated in a nonregenerative and unsaturated linear mode. If the oscillator frequency coincides exactly with the amplifier frequency, all sidebands of the phase-modulated signal will receive balanced amplification and there will be no fundamental-frequency FM-AM conversion in the amplifier However, if the oscillator frequency deviates from that of the amplifier, the FM sidebands will receive unbalanced amplification and there will be some FM-AM conversion in the amplifier. The output will then contain an AM component at the modulation frequency f_m, which will be sensed by a photodetector.

The amount of AM detected will vary linearly with frequency deviation over a reasonable range. This component provides a useful error signal to indicate frequency deviation from atomic line center. The laser oscillator frequency can then be corrected by standard feedback techniques using thermal, magnetorestrictive, or piezoelectric tuning.



Source: A. E. Siegman of
Sylvania Electronic Systems
under contract to
Marshall Space Flight Center
(MFS-2559)

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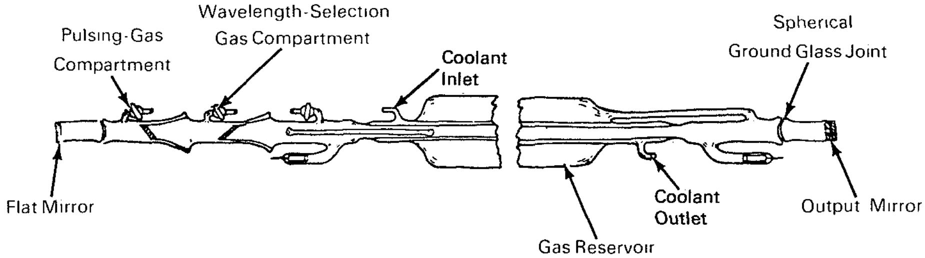
REPETITIVELY PULSED, WAVELENGTH-SELECTIVE CO_2 LASER



A new CO_2 laser provides a simple, portable source of coherent light pulses at selected infrared wavelengths. Originally designed for air pollution detection, other potential applications include optical communication and research in infrared transmissive materials. This laser is designed for sealed operation and high-power repetitive pulsing at selected wavelengths.

Earlier systems for pulsing a CO_2 laser employed prisms or gratings within the laser cavity to shift the output from one infrared line to another. However, these systems are cumbersome and difficult to manipulate, and also significantly lower in power output.

This improved CO_2 laser operates with two gas absorption cells built into the cavity. The first contains a gas which controls the wavelength of emission. The second contains a gas which forces the laser into high-frequency pulsed mode operation. The pulsing and wavelength shifting are caused by the spectroscopic and kinetic properties of the gases. With proper choice of absorbing gases, high-powered pulsed operation at repetition rates of up to 100 kHz has been achieved at various wavelengths between 9.08 and 10.6 microns.

The illustration diagrams a model which has been operated with an output of up to 25 watts. The main body of the laser consists of three concentric glass tubes. Laser action occurs in the inner tube. Cooling water flows through the middle tube. The outer tube is a gas reservior. Standard taper joints permit extra gas compartments to be included within the laser cavity. The operating gas mixture consists of 85 percent helium, 10 percent nitrogen, and 5 percent carbon dioxide at a total pressure of 8 Torr. Without wavelength control, normal CO_2 emits a 10.6 micron line, and CO_2 containing the oxygen-18 isotope emits a 9.3-micron line. With wavelength-control gas compartments added, the laser has been pulsed at 10.6 microns with propylene gas, at 9.2 microns with formic acid vapor, and at various wavelengths with CO_2 gas itself. Mixtures of CO_2 gas and propylene have also been used.

Source: P. L. Hanst
Electronics Research Center
(ERC-10178)

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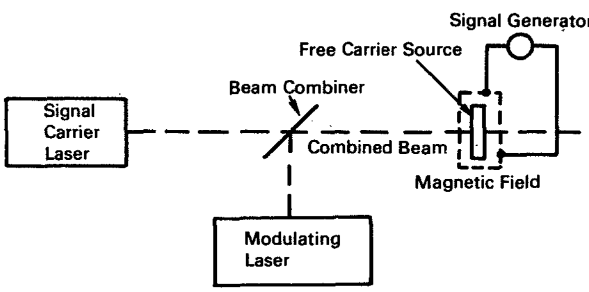
OPTICALLY INDUCED FREE-CARRIER LIGHT MODULATOR



A system has been devised to modulate a signal-carrier laser beam with a second laser beam of different frequency which acts on a free-carrier source through which the carrier beam is directed. The second beam affects the transmission characteristics of the free-carrier source, thus modulating the signal carrier beam.

Many efforts are being made to develop a modulated laser-beam communications system. Many devices have been used to modulate laser beams, but most have inherent disadvantages. For example, electro-optical and magneto-optical modulators require large amounts of drive power per unit bandwidth. Optical waveguides and electrically depleted free carrier modulators suffer from low power handling capabilities and low modulation indices. Electro-acoustic modulators are limited by narrow information bandwidths, while band-gap modulators have low modulation indices. As a result, modulators of these types have found only limited use.

This invention provides a laser beam modulating system with low drive-power requirements per unit bandwidth. Referring to the illustration, the signal-carrier laser generates a signal to which the light beam combiner is transparent, while the modulating laser generates a beam to which the light beam combiner is reflective. By positioning the combiner as shown, the two laser beams join on a mutual axis to form a combined beam that impinges on the free carrier source. The free carrier source is transparent to the signal portion of the combined beam but relatively opaque to the modulating portion. This is due to the difference in wavelength of the two beams plus the constituent makeup of the free carrier source (a situation similar to the beam-to-combiner relationship).

Radiation from the modulating laser creates free carriers (relative to its wavelength) in the free carrier source to vary its degree of transparency to the signal-carrier laser beam, thus modulating the latter. Control of the spatial distribution of the signal-carrier beam is achieved by application of a dc magnetic field along the direction of propagation of the modulating light signal. This restricts free carrier diffusion to a path parallel to the direction of propagation of the modulated light.

Source: W. E. Richards and C. L. Gruber
Goddard Space Flight Center
(GSC-10216)

No further documentation is available.

NEON ISOTOPES USED TO CANCEL FREQUENCY-PUSHING ERRORS

A mixture of approximately equal volumes of neon 20 and neon 22 (or other pairs of neon isotopes) in the neon portion of the helium-neon discharge tube may be used to cancel frequency-pushing errors arising from unequal (nonreciprocal) gain in the two contracirculating beams in a ring laser.

Each neon isotope exerts a frequency-pushing effect on the laser operating frequency. As the two isotopes' spectral-line center frequencies lie on opposite sides of the operating frequency, the pushing effects are in opposite directions; hence they cancel. Also, because of the mixed neon isotopes, the central portion of the laser's gain-vs-frequency curve has a smooth, simple maximum. The laser frequency can be stabilized at this maximum by applying a slight frequency dither and synchronously detecting the resulting amplitude modulation.

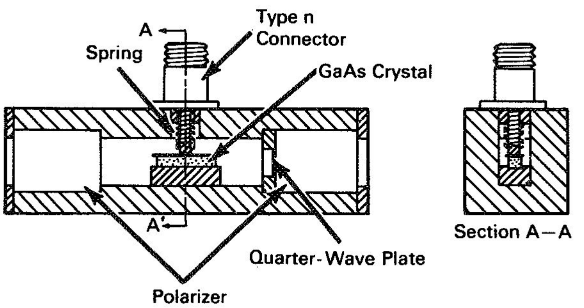
Source: W. M. Macek, R. W. Olthuis,
and J. R. Scheneider of
Sperry Gyroscope Company
under contract to
Marshall Space Flight Center
(MFS-1476)

No further documentation is available.

GALLIUM ARSENIDE ELECTRO-OPTIC MODULATOR

An electro-optic modulator incorporating a large gallium arsenide (GaAs) crystal, a mica quarter-wave plate, and two calcite polarizers, can be used to amplitude- or phase-modulate an infrared laser beam of wavelength 1 to 3 microns. In this range, modulation depths greater than 50 percent are achieved over a bandwidth from dc to above 300 MHz with an applied voltage of 400 rms.

The large single crystals of gallium arsenide were grown by the horizontal Bridgeman technique. They have uniformly high resistivities (exceeding 10^6 ohm cm), are strain-free, and are comparable in quality to good optical glass. The small size and poor quality of most electro-optical crystals previously available have limited their usefulness as laser modulators.



The illustration shows cross sections of a complete modulator unit. The GaAs crystal presents a 3 picofarad capacitive load to a 50 ohm coaxial line. Openings in the mount for passage of the laser beam are cutoff waveguides at the modulation frequencies to prevent radiation of the modulating signal. The angular aperture of the device (greater than 12 degrees) is limited by the 1-centimeter aperture of the polarizers. Wavelength response of the modulator can be shaped by using different wave plates. The operating wavelength can be increased by proportionately increasing the operating voltage.

Source: T. E. Walsh of
Radio Corp. of America
under contract to
Goddard Space Flight Center
(GSC-10686)

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DEVELOPMENT OF A RING LASER

Research on a ring laser system has resulted in the development of a successful rotation sensor and in the conception of several new techniques for measuring important optical effects. The supporting documentation generated by this project

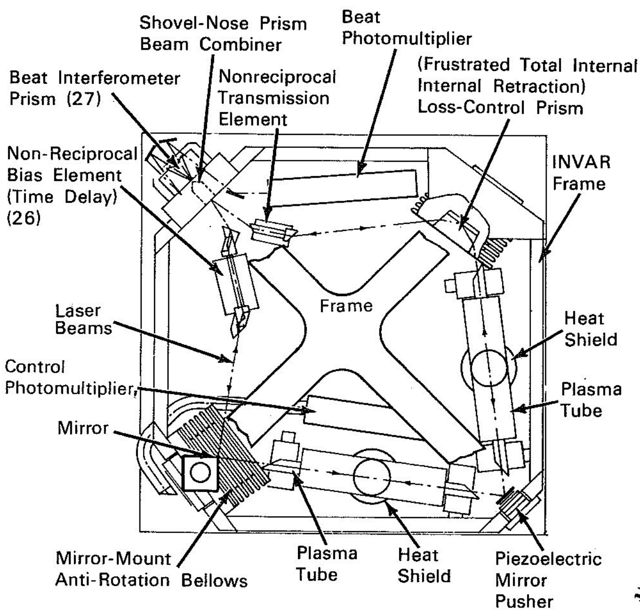

Figure 1 Ring Laser Optical Configuration

is in effect a reference work on the theory, operation, design and application of ring laser systems.

The instrument and its components are de-

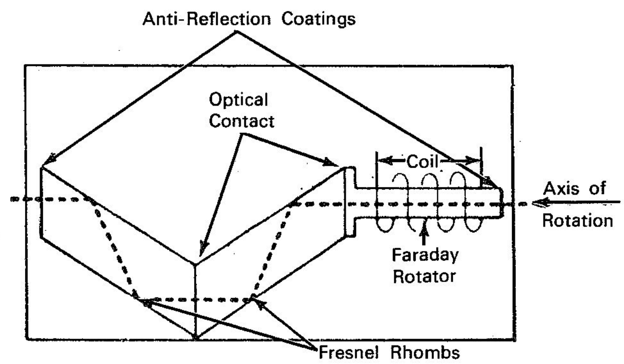

Figure 2 Nonreciprocal Transmission Control

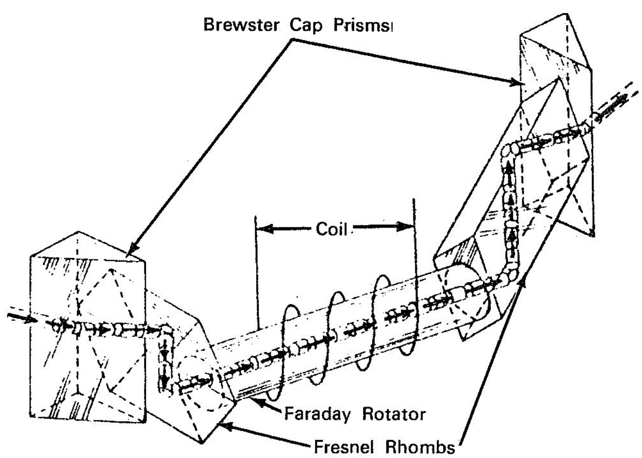

Figure 3 Nonreciprocal Index Control

scribed in detail, including various subcomponents which control system gain, nonreciprocal time delay, nonreciprocal transmission, and overall loss. The use of a ring laser as a rotation sensor is investigated and recommendations are made on the possibility of using the ring laser to investigate many types of nonlinear phenomena in optics. These include effects related to the Fizeau drag of a moving dielectric and the Faraday effect of a magnetic field.

An overall figure is presented to show the optical configuration of the ring laser (Fig. 1). Several of the individual optical elements of the ring are further described in the following paragraphs, and additional devices conceived for possible use with the ring laser are described in several subsequent items.

Nonreciprocal Transmission Control

The difference between the power levels of the clockwise and counterclockwise beams can be adjusted by changing the solenoid current generating a longitudinal magnetic field in the device diagrammed in Figure 2.

The nonreciprocal transmission control is a mechanically rotatable, half-wave retardation element composed of two Fresnel rhombs in tandem, followed by a magneto-optic Faraday rotator. It functions as follows: the Fresnel rhombs rotate the planes of polarization of the clockwise and counterclockwise beams in opposite directions. The magneto-optic element rotates the planes of polarization in the same direction. For a given setting of rhomb angle and solenoid current, these rotations add for one beam and subtract for the other. The additive direction suffers higher losses at the Brewster's angle surfaces in the resonator.

Nonreciprocal Index (Time Delay) Control

The frequency splitting between clockwise and counterclockwise modes of the ring laser can be controlled by changing the current in the solenoid of another magneto-optic element, shown in Figure 3. The two plane-polarized light beams enter the Fresnel rhombs through attached Brewster's angle faces and are converted to circularly polarized light by two total internal reflections. Then the beams pass through a section of fused silica in the longitudinal magnetic field generated by the surrounding solenoid. In this section the index of refraction differs for the two directions of propagation.

With this unit, nonreciprocal optical path lengths of up to $\pm 10^{-3}$ λ, have been produced, causing mode splittings of ± 350 kHz in the ring laser. Fifty kHz was sufficient to eliminate mode-locking effects between the two modes, except when intensity competition occurs at the center of the Doppler line. The stability of the frequency splitting introduced by this device was about $\pm$ 25 Hz.

Perimeter Tuning Control

The mean frequency of the clockwise and counterclockwise modes can be tuned across a Doppler line by a piezoelectric actuator which moves the flat mirror through a range of ± 3 orders. Its frequency response permitted saw-tooth scanning of the mean laser frequency at repetition rates from 0 to 5 kHz. Typical mean laser-frequency scanrate was 2 GHz per sec. The frequency sweep voltage was displayed on the horizontal trace of an oscilloscope, and various laser performance parameters were plotted as a function of mean laser frequency. In all plots, the longitudinal mode spacing and the center of the Doppler line could be clearly identified. Hence, direct measurements of laser frequency with respect to the Doppler line were possible. With this device, several properties of single mode ring lasers could be studied.

Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14036)

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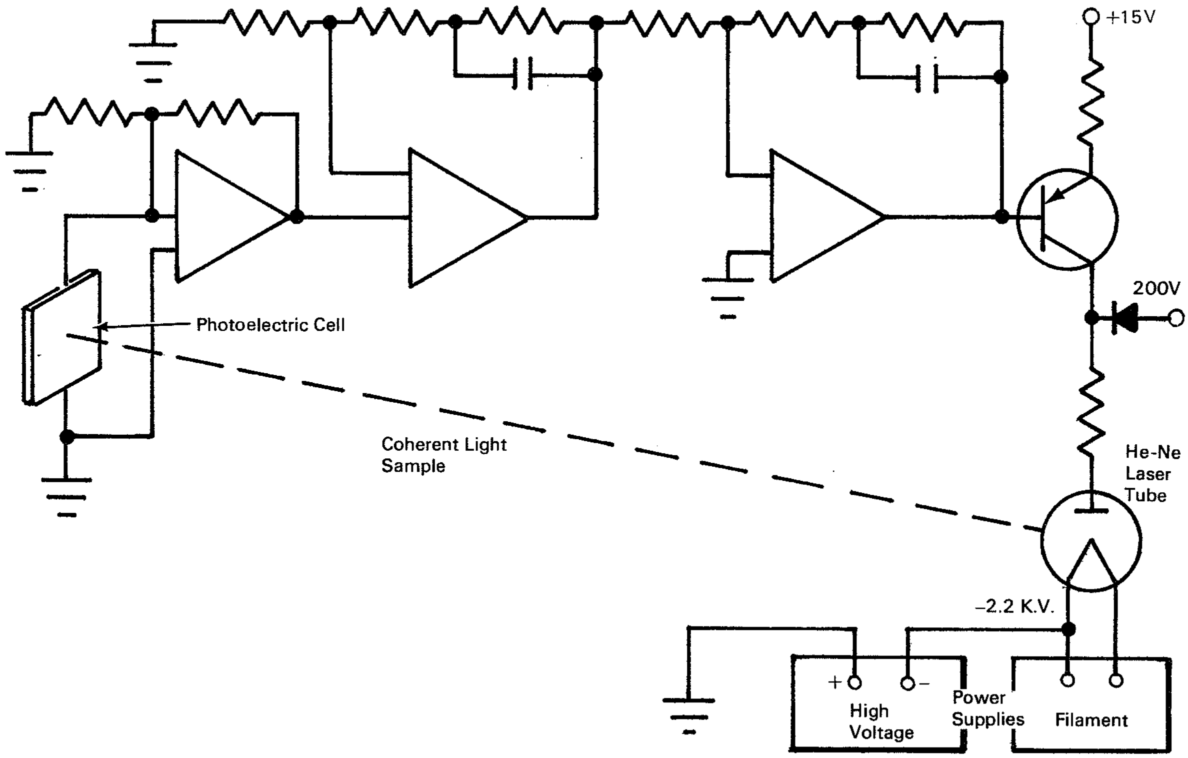
LASER INTENSITY REGULATOR

The beam intensity of a laser has been regulated electronically with a circuit which controls the laser anode current. In the circuit illustrated, a photoelectric cell converts a small sample of the



laser output to an electric signal which is applied to an amplifier chain. A high voltage PNP transistor is used as the laser anode drive.

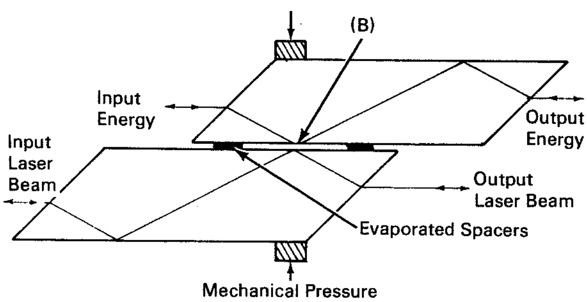
With the system shown, net loop gain was 46 dB, breaking at 1 kHz and 10 kHz and falling to zero dB at 0.1 kHz and 100 kHz. Beam intensity fluctuations were held within one part per thousand. Use of small, integrated circuit feedback amplifiers for the majority of the amplification chain yielded compactness and high stability for the control loop.

Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14039)

No further documentation is available

VARIABLE INPUT/OUTPUT COUPLERS FOR RING LASERS

For coupling energy into or out of a ring laser cavity, it is often convenient to use a device with variable coupling. This need frequently arises in situations dealing with longitudinal mode control, alignment of secondary optical systems, and laser frequency or phase control. Such a device, which has the additional advantage that it does not deflect the beam into which it is introduced, is illustrated.



The ring laser beam enters the lower prism at Brewster's angle and undergoes two total internal reflections before exiting, again at Brewster's angle, on a course parallel to its original direction of travel. At the site of the second reflection (labeled "B" on the figure), a second, identical prism is placed in close proximity to the first.

With the adjacent reflecting surfaces separated by evaporation-deposited spacers approximately one wavelength in thickness, the total reflection is partially frustrated, and energy is transmitted from one prism to the other. The amount of coupling may be varied from zero to almost 100% varying the gap width. One technique involves the application of mechanical pressure, as shown on the figure.

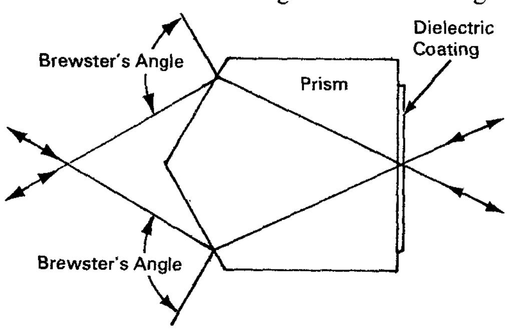
Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14038)

No further documentation is available.

SHOVEL-NOSE PRISM INPUT/OUTPUT COUPLER

Another means of coupling energy into or out of ring-laser cavities, especially useful in applications where it is desirable to deal with beams converging at a slight angle, is shown in the figure below.

Beams enter from the right at a small angle (10



to 15 degrees) away from normal incidence, and leave at the left through Brewster's angle surfaces. The angle between the beams can be varied slightly, to fit various ring-laser geometries, and a curved surface may be used at the input to the prism as a focusing element. Because of the low losses introduced by the Brewster's angle surfaces, the top or bottom half of the prism may be placed inside a ring laser resonator.

Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14044)

No further documentation is available.

LASER BEAM DIAMETER CONTROL

A recurring problem in ring laser design is loss caused by scattering and optical inhomogeneity of materials needed inside the resonator. The beam in a ring laser makes the problem even more critical in ring lasers than it is in linear lasers, because the beam in a ring laser makes only half as many passes through the active medium. The problem is partly solved by using properly spaced curved mirrors to control the beam diameter in the laser cavity. If, for instance, two mirrors are separated by a distance equal to the sum of their focal lengths, a converging beam will be produced between them, while essentially parallel beams may be maintained elsewhere in the system. Critical components may be inserted near the focus, where the beam cross section is a minimum. Other combinations of spacing and focal length may also be used to enlarge or decrease the cross section of the beam.

Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14040)

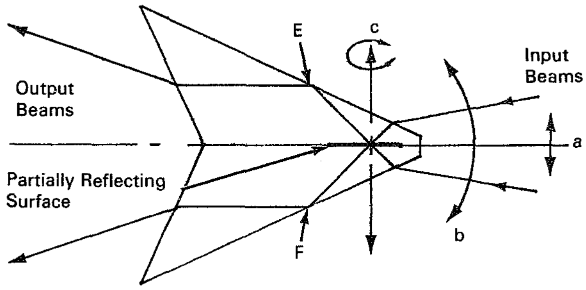
No further documentation is available.

OPTICAL BEAM COMBINER

Investigation of the phase and frequency of the contracirculating beams in a ring laser often requires their combination in some type of interferometer. The combining must be done in a stable structure which does not introduce spurious phase shifts itself, or couple energy from one beam to the other inside the laser cavity. A structure meeting these requirements is shown below. It is specifically designed to work with the coupling prism described in the preceding item, but could be modified to work at other angles. All input and exit surfaces are at Brewster's angle to the beams. The partially reflecting surface coating is at a cemented interface and is protected from damage.

Three mechanical motions are required to align the beams: translation (a), which serves to bring the beams to the same point on the partially reflecting surface; rotation (b) about the point of intersection of the beams in the horizontal plane; and rotation (c) about the same point, but in the vertical plane. The latter two motions are sufficient to make the beams colinear after they have been made to intersect at the beam-splitting surface.

A total internal reflection of each pair of combined beams occurs at points E & F. This allows the beams to be extracted at Brewster's angle, and avoids ghost reflections from the surfaces.



Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14043)

No further documentation is available.

FACTOR OF MERIT FOR FARADAY ROTATION

Light intensity in a ring laser cavity is often controlled by rotating the plane of polarization. This is most frequently accomplished by using the Faraday effect in a transparent material. However, many such materials, including most glasses, introduce too much loss from bulk scatter and absorption to permit their use in a laser cavity. Fused silica, which gives minimum losses, also shows low Faraday rotation.

Many types of glass have been investigated in an attempt to find a more suitable material. Samples approximately 1-in. thick with polished parallel faces were placed at Brewster's angle inside the resonator of a ring laser. The ring used had a perimeter of 7.5 meters and was powered with a single 80 cm long $\times$ 4 mm diameter plasma tube. Only two glasses were found that allowed the laser to operate. These were Schott glass types SK-16 and F-2, which showed estimated relative scatter factors of 5 and 2, respectively, and allowed laser operation at power factors (relative to operation with no sample) of 0.01 and 0.1, respectively.

Source: P. H. Lee and G. Dueker of
Perkin Elmer Corp.
under contract to
Marshall Space Flight Center
(MFS-14035)

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IMPROVED RESOLUTION OF A RING LASER ROTATION SENSOR

The sensing resolution of a gas ring laser in a gimballess gyroscope or inertial rotation sensor has been improved. Mode coupling between the two contracirculating traveling waves, caused by scattering from imperfections within the ring, is minimized by oscillating the laser radiation sources at a high frequency. Several other methods of minimizing mode coupling effects have undesirable operating characteristics for use in a rotation sensor.

In this method, piezoelectrically driven corner mirrors of the ring laser are oscillated in a direction parallel to their surfaces and to the plane of rotation. Thus the scattering centers are periodically displaced, resulting in rapid phase variation of the scattered light. Resonant oscillations may be sustained at frequencies of 1 or 2 MHz, with amplitudes of fractions of a micron. Under these conditions, the rms velocity of each mirror would be measured in tenths of a meter per second, with a resultant rms Doppler shift in the scattered light of about one MHz from the optical frequencies of the traveling waves. Phase variation of the scattered light occurs at a much greater rate than that achieved by previous methods, but the transverse motion of the mirrors does not shift the traveling-wave sustained oscillations. This method applies to both volume and surface scattering from mirrors and Brewster plates.

Source: J. D. Coccoli and J. R. Lawson of
Massachusetts Institute of Technology
under contract to
Manned Spacecraft Center
(MSC-11584)

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